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SHORT COMMUNICATION

An alternative method for determining the body condition index of the free-living South American coati

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Abstract

Assessing and monitoring the welfare of free-living mammals is not a usual process due to the logistical complications associated with their capture and sedation, collection and storage of biological samples and their release. In this context, non-invasive methods for monitoring wildlife constitute a good alternative approach for *in situ* conservation. Body condition index, as a measurement of health status, has been used in free-living mammals; its low value may be associated with negative effects on reproduction and survival. The present study aimed to generate an alternative and reliable non-invasive method and then determine the body condition index, based on previously-collected biometric measurements, without the need to capture and immobilise the animals. A total of 178 free-living *Nasua nasua* Linnaeus, 1766 were trapped, weighed and measured. Statistical methods were used, based on Boosted Regression Trees (BRT) using body mass, biometric measurements (body length, height and chest girth) and gender as explanatory variables. To assess the agreement between the real Body Condition Indices (BCIs) and the predicted values of BCIs, we explored the correlation between each model using the Bland-Altman method. This method showed a strong agreement between the predictive BRT models proposed (standardised residuals from a linear regression between body length and chest girth) and standardised residuals (linear regression between body mass and body length). The results obtained herein showed that BRT modelling, based on biometrical features, is an alternative way to verify the body conditions of coatis without the need to capture and immobilise the animals.

Keywords
Biometrics, Boosted regression trees, *Nasua nasua*, welfare, wildlife

Monitoring of wildlife health is important in investigating possible threats (e.g. diseases and population decrease) to animals and the establishment of conservation strategies. The health of wild animals, at the population or individual levels, depending on the question to be answered (Leroy et al. 2017) and body condition measurements, are fundamental data of the life history of free-living animals (Stephen and Duncan 2017). Indeed, the body condition reflects the nutritional state, expressed by a broad energetic challenge and has been used as an index in assessing well-being (Morellet et al. 2007). In fact, when evaluating body conditions, the use of length-to-weight comparisons to assess individual energy reserve is a reliable reflection of an individual's foraging ability and success (Bradford et al. 2012). In this context, the monitoring of body conditions is an essential tool in wildlife management, as well as in measuring the population performance and detecting possible imbalances before serious problems arise.

The determination of the body condition of many animal species in the wild, such as large carnivores, rare or tree-dwelling species and those that develop capture stress is a challenge (Huber et al. 2017; Lambert et al. 2012). Captured and chemically-immobilised individuals can succumb (Chinnadurai et al. 2016) and, for rare species, it is difficult to obtain an adequate sample size for body and weight measurements (Law et al. 2016; Turner et al. 2016; Fukuda et al. 2013); thus, it is necessary to use a new non-invasive method for evaluating body conditions, avoiding the capture and immobilisation of animals. Camera trapping has emerged as a powerful tool for monitoring carnivores in their natural habitats (Karanth and Nichols 2011; Sollmann et al. 2013; Burton et al. 2015) and has been used in determining biometric and morphometric measurements of free-living mammals (Van Rooij and Videler 1996; Pfister and Goulet 1999; Lambert et al. 2012; Shumba et al. 2017). Thus, the main objective of the present study was to establish an alternative and reliable non-invasive method, based on biometric measurements for determining the body condition index of the free-living South American coati (*Nasua nasua* Linnaeus, 1766).

This study was carried out between March 2018 and February 2019, in a forest fragment, located in the City of Campo Grande, Mato Grosso do Sul, Brazil (Fig 1; Map of the study area). A total of 178 coatis were trapped. We used 60 box-traps (90 × 45 × 50 cm), baited with bacon and tinned sardines to capture the target species. Once trapped, the animals were sedated with an intramuscular injection of Zoletil 50 (containing tiletamine hydrochloride and zolazepan hydrochloride, 10 mg/kg) and marked with subcutaneous transponders. All animals were weighed with a precise and handy spring balance (Pesola) (body mass [g]) and measured with a precision caliper 0–600 mm (Mitutoyo) (head-body length [mm], height [mm] and chest girth [mm]). The sex of all the animals was recorded and only adult individuals were evalu-

Figure 1. Location of the study area in the Municipality of Campo Grande (red point), Brazil.

ated. The animals were released at the capture site after recovery from anaesthesia. All field procedures were conducted in accordance with a licence granted by Chico Mendes Institute for Biodiversity Conservation (n° 56912-2). The present study was approved by the Ethics Committee for Animal Use of Dom Bosco Catholic University, Campo Grande, MS (n° 001/2017).

In order to determine a method for measuring the body condition of coatis without capturing or manipulating the animal, a statistical approach, based on Boosted

Regression Trees (BRT) using biometric measurements (head-body length, height and chest girth) and gender as explanatory variables, was used. First, an initial model using biometric measurements of head-body length, height and chest girth was created with all the explanatory variables proposed to predict body condition. Two free parameters ("learning rate" and "tree complexity") were fixed according to Elith et al. (2008). The number of trees, the estimated deviance in the final BRT model and the final number of explanatory variables, which was inclusive, were calculated using a 10-fold Cross-validation technique (Hastie et al. 2009). Subsequently, to evaluate the influence of single or multiple explanatory variables for prediction, sequential models were created following a similar procedure, removing one or more of the initially-proposed variables, based on their relative importance for each model. Additionally, the real Body Condition Indices (BCIs) assessed variation in body condition, based on the standardised residuals from an ordinary linear regression between body mass (g) and head-body length (mm) of individuals, while accounting for age and sex effects. In addition, all samples are independent and the outliers have been removed. This should circumvent the effects of animal growth on the condition index. Therefore, the residuals were calculated for males and females separately, all samples being independent (Santos et al. 2018). Once all these models were obtained and optimised, we used the Bland-Altman method to assess the agreement between the real BCIs and the predicted values of BCIs (Bland and Altman 1999). All the statistical calculations were carried out using R software 3.4.2 version (R Development Core Team 2015) and the packages "gbm" (Ridgeway 2013) and "BlandAlmantLeh" (Bernhard 2015). P-values lower than 0.05 were considered statistically significant.

We obtained a final estimation model of BCIs that included all the explanatory variables proposed (Model 1: chest girth, head-body length, height and sex [Table1]) and a final body condition predictive model that showed a deviance percentage of explained 81%. Chest girth and head-body length had the greatest influence (43.6% and 31%, respectively), showing a positive correlation with the BCIs. BRT models, obtained after removing one (Model 2: chest girth, head-body length and height [Table 1]) and two (Model 3: chest girth and head-body length [Table 1]) of the explanatory variables proposed, showed a percentage of deviance explained between 75% and 71%, respectively (Table 1). The chest girth had the greatest influence in all models (Model 1: 43.6%; Model 2: 54% and Model 3: 61.3%) showing a positive correlation with body condition predictive. The Bland-Altman method showed a strong agreement between the BCI results of the predictive BRT models (standardised residuals from a linear regression between chest girth and head-body length) and the real BCIs (standardied residuals from a linear regression between body mass and head-body length). These two quantitative measurements have low bias values (-0.012 to 0.012), with a difference close to zero. Bias close to zero demonstrates a greater agreement between the methods; if not close to zero, it indicates that both methods are producing different results (Fig 2; Bland-Altman plot).

Results obtained in this work showed that BRT modelling, based on biometric features, is an easy method for measuring the body condition of coatis without having to manipulate the animal, replacing the most commonly used body condition

Table 1. Results obtained with Boosted Regression Trees (BRT) modelling, based on biometric features of the South American coati. Information about technical parameters (learning rate (lr) and tree complexity (tc)), number of trees (Trees), percentage of deviance explained (% Dev) and relative importance (% RI) of the variables used in BRT models predicting the body condition of coatis.

Body Condition Indices (Standardised residuals)				
Proposed variables	**Parameters**	**Tree**	**%Dev**	**%RI**
Model 1				
Head–Body Length + Chest Girth + Height + Sex	lr = 0.01 Tc = 3	1100	81	Chest Girth = 43.6 Head- Body Length = 31 Height = 18.7 Sex = 6.8
Model 2				
Head–Body Length + Chest Girth + Height	lr = 0.01 Tc = 2	1150	75	Chest Girth = 54 Head-Body Length = 34.5 Height = 11.5
Model 3				
Head–Body Length + Chest Girth	lr = 0.01 Tc = 1	1500	71	Chest Girth = 61.3 Head-Body Length = 38.7

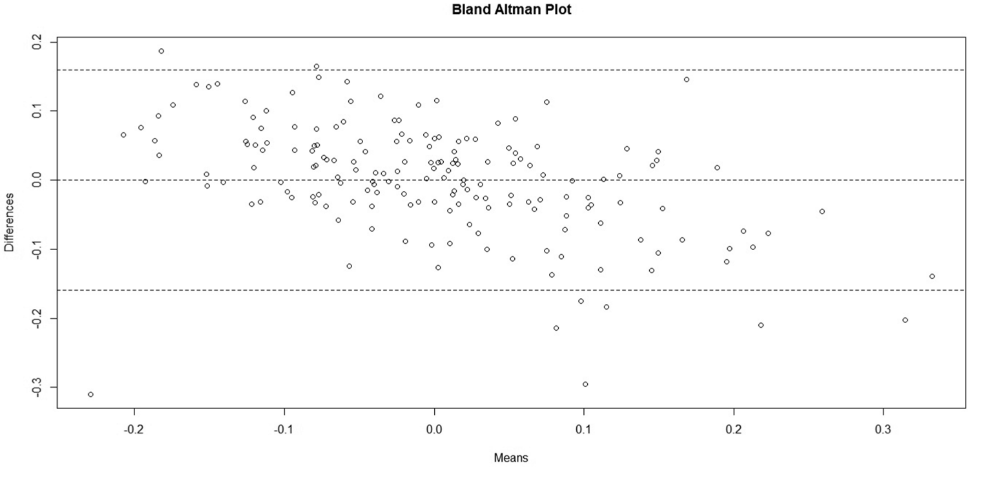

Figure 2. Bland-Altman plots showing the agreement between real body conditions of the South American coati and the predictive values obtained by Boosted Regression Trees models using a different set of explanatory variables. X axis represents the difference between real body conditions and the predictive value. Y axis represents the mean of the real body conditions and the predictive value.

indices (standardised residuals from a linear regression between body mass and head-body length) (Fig 3; Regression Graph) (Santos et al. 2018). In fact, the combination of a set of morphometric measurements yields between 81%, 75% and 71% of the observed variability in the BCIs. The BRT method has been widely used to generate predictive models in ecological and biological studies and is a useful tool for working on common ecological problems (Gonçalves et al. 2016; Dormann et al. 2013; Elith et al. 2008). This methodology was used to predict the body fat in wild boar (*Sus scrofa*) by Risco et al. (2018), demonstrating that it can be applied to analyse different taxa of wild mammals. Unlike simple regression trees, the BRT

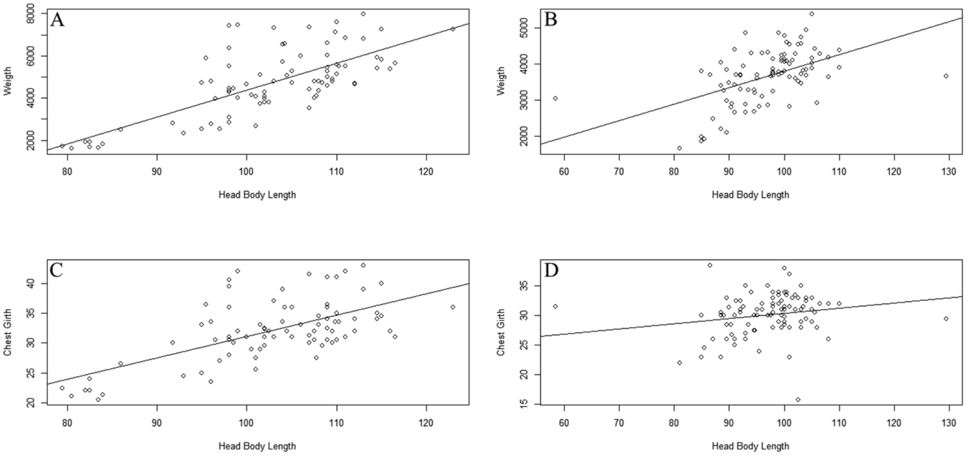

Figure 3. Regression graphs showing the agreement between head-body length (mm) and body mass (g) (**A, B**) or chest girth (mm) (**C, D**) of the South American coati, considering males (**A, C**) and females (**B, D**).

model allows a better understanding of each parameter; it measures the contribution of each variable of the final model and shows the most important variables (Hastie et al. 2009; Elith et al. 2008). Furthermore, the best predictive BCI values showed an agreement with the real BCIs when a conventional measurement method (Fig. 2; Bland-Altman plot) (Bland and Altman 1999) was used for comparison. The Bland-Altman method is used to evaluate the agreement of continuous measurements using a graphical method and the Limits of agreement (Bland and Altman 1986, 1995; Zaki et al. 2012;).

Body conditions of wild animals can be measured through their capture and chemical immobilisation, but these often disrupt their natural activities and cause stress. Moreover, their sample sizes are generally small and have a low representability (Deka et al. 2012; Huber et al. 2017; Braud et al. 2019). However, if the remote acquisition of morphometric data using camera traps is possible, data regarding welfare of wild populations can be more reliable. In fact, studies on many wild mammals using photographs can optimise the efforts of biological research (Van Rooij and Videler 1996; Pfister and Goulet 1999; Oliveira-Santos et al. 2008; Lambert et al. 2012; Leuchtenberger et al. 2014; Shumba et al. 2017; Mahendiran et al. 2018). Therefore, the next step is to validate our analysis using the means of measurements made by camera traps, to show the efficiency of the technique. We provided evidence that the body conditions of free-living South American coatis can be obtained by measuring chest girth and head-body length with great accuracy. Since low values of body conditions due to parasitism can negatively influence reproductive rates, movement, haematological indices and survival of infected hosts (Schwanz 2008; Robar et al. 2010; Santos et al. 2018), this methodology is a tool that has the potential to objectively monitor free-living mammals.

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